ART. II. — 1. *Observations and Discussions on the November Meteors of* 1867. United States Naval Observatory, Washington. 8vo pamphlet.
2. *Meteoric Astronomy.* By DANIEL KIRKWOOD, LL. D. Philadelphia. 1867. 12mo.
3. *A Treatise on Meteorology. With a Collection of Meteorological Tables.* By ELIAS LOOMIS, LL. D. New York. 1868. 8vo.

IF we watch the heavens on a cloudless night, we shall frequently see an appearance as of a star suddenly coming into view, moving rapidly for a second or so, and as suddenly disappearing. These appearances may be seen three or four times an hour in the evening, and they gradually increase in frequency throughout the night. They have been seen from time immemorial, and are familiarly known as shooting-stars. In general they are so minute as hardly to attract attention. But they sometimes have fallen in such numbers as to fill the beholders with terror, and alarm them with the notion of the end of the world. We have in the annals of India and China records of such showers of meteors extending back to a very remote period. The researches of Edward Biot, Quetelet, Professor H. A. Newton, and others, have brought to light many of these old accounts, some specimens of which we shall present to the reader.

An Arab historian says: "In the year 599, on the last day of Muharram, stars shot hither and thither, and flew against one another like a swarm of locusts; this phenomenon lasted until daybreak; people were thrown into consternation and made supplication to the Most High; there was never the like seen except on the coming of the messenger of God, on whom be benediction and peace."

Another record says, that in the year 763 "the stars were suddenly seen to fall from the heavens in such numbers that people were frightened, thinking the end of the world had come."

On the 21st of October, 855, "a great fall of stars occurred

during the night, lasting from evening till daylight. At the same time there were earthquakes throughout the world."

The years 1094, 1095, and 1096 are remarkable for the recurrence of meteoric showers on the same dates in each. On the 10th of April, 1094, "stars were seen to fall from the heavens in such numbers that they could not be counted." In the following year they "fell like hail" from midnight until daylight on the 10th and 11th of the same month. The council of Clermont was then engaged in planning a crusade, and when the shower was found to spare the earth, it was concluded to betoken some great revolution in Christendom. Again, in the year 1096, on the same date, the stars "flew like dust in the wind, from cock-crowing till daylight."

"October 19, 1202.—The stars flew like grasshoppers from east to west. This lasted until daylight. The people were in distress."

In one of the old annals of Portugal there is an account which is remarkable for its accordance in certain respects with the modern theory of the November showers.

"In the year 1366, on the 22d of October, three months before the death of the king Don Pedro, there was in the heavens a movement of stars such as men never before saw or heard of. From midnight onward, all the stars moved from east to west; and afterward they fell from the sky in such numbers, that, as they descended low in the air, they seemed large and fiery, and the sky and the air seemed to be in flames, and even the earth seemed ready to take fire. Those who saw this sight were filled with great fear and dismay, thinking they were all dead men, and that the end of the world had come."

That part of the heavens toward which the earth is moving rises at midnight, and crosses the meridian at six in the morning. This is also the point from which the meteors appear to come. Hence soon after midnight the meteors appear to move from east to west, while about daylight they fall from near the zenith like rain, in exact accordance with the above description.

Coming down to the times of more accurate observation and description, we find certain periods of the year to be remarkable for the frequency of meteors. The August meteors have been

inferior only to those of November in numbers and brilliancy. In the year 268, in 859, and in 1451, star showers are recorded by the Chinese historians as occurring in August. About the 9th of August, 1798, Dr. Noah Webster observed great numbers of meteors in Hartford during several nights. They moved from northeast to southwest, and succeeded each other so rapidly as to keep the eyes of the spectator constantly engaged. And, in almost every year since, about the same date, a similar phenomenon has been seen on a small scale, so that the August meteors are now as well known as those of November. The shower in August is not on a great scale, but several hundred meteors may usually be counted on the night of the 10th and 11th.

The November showers have lately been the object of special study, not only on account of their peculiar brilliancy, but because of the interest attaching to the recurrence of their period. The shower seen by Humboldt and Bonpland from the Andes, on November 12, 1799, and described in the narrative of Humboldt's travels, is well known. On the night of November 13, 1833, a display which, from all accounts, must have been one of the greatest on record, was seen in this country. Throughout the South the negroes, like the Europeans of a previous century, thought the end of the world had come at last. It was carefully observed at New Haven by Professor Olmsted. He was the first to elaborate a theory of the cause of the phenomenon; and though his ideas are now known to be fundamentally erroneous, they contained some elements of truth.

The recurrence of the shooting-stars thirty-four years after they had been seen by Humboldt on almost the same date, suggested to Olbers the idea of a thirty-four year period, and led him to predict their return in 1867. The idea was elaborated, and its correctness proved by Professor H. A. Newton of Yale College. The thoroughness with which this gentleman has investigated the subject of shooting-stars, particularly those of November, has rendered him pre-eminent in this department of astronomy. Collating the accounts, he found a long series of recorded apparitions at intervals of one third of a century, extending, with many breaks, from A. D. 931 to 1833.

The exact date of appearance, however, instead of being uniform, changed with considerable regularity. The shower of 931 was described as occurring on the last day of Muharram, in the year 599, according to the Arab chronology, which corresponded to the 19th of October. The successive showers appeared at a later and later date until the present time, when they occur on November 13. This change indicated a secular variation in the orbits of the group of bodies causing the showers, and was the means of fixing the position of the orbit.

Before the observations and researches of Professor Olmsted, absolutely nothing was known of the origin and causes of these phenomena. It was not even decided whether they were of cosmical or terrestrial origin, whether they came from the planetary spaces or were caused by electricity or other agents in the atmosphere. It is a little singular that so great an explorer and lover of nature as Humboldt should have failed to decide this question by his own observations, since we now know that the data for that decision must have been plainly presented to his eyes. Careful observation would have shown him that the lines of motion of the meteors, when produced backward, all passed near the star γ Leonis, and that the point of intersection seemed to follow this star as it approached the zenith, thus showing that the direction of the meteor-fall did not follow the diurnal rotation of the earth, as it would if the meteors originated in the atmosphere. But he did not appear to suspect that the phenomenon was anything more than a local one, and it was left to observers thirty-four years later to show that it was not a meteorological, but an astronomical one.

The great shower of 1833 was accounted for by Professor Olmsted on the hypothesis of a light nebulous body moving in an orbit within that of the earth, and sometimes coming into contact with the latter. He conceived it to consist of light combustible matter, which, when it entered the atmosphere, powerfully condensed the air before it, and thus elicited the heat which set it on fire. The fate of this hypothesis may serve as a warning to philosophers in forming suppositions relating to causation, to assign no cause which is not a real phenomenon, and susceptible in its own nature of being proved by other

evidence. The "nebulous body" of Professor Olmsted was as hard to account for as the meteors themselves, and he had no other evidence of its existence than that it explained the phenomena of meteoric showers. With the progress of science it has vanished entirely, and a cause has been discovered, which accounts not only for shooting-stars, but for fire-balls, aerolites, and telescopic comets. It is only within the last year that the new theory has been perfected and elaborated, and until the recent publication of the works named at the head of this article, no complete and intelligible statement of it was accessible to the general reader. Such an explanation we shall now endeavor to give.

The fundamental idea of the theory is this: The planetary spaces are crowded with immense numbers of bodies, which move around the sun in all kinds of erratic orbits, and which are too minute to be seen with the most powerful telescopes.

If one of these bodies is so large and firm that it passes through the atmosphere and reaches the earth without being dissipated, we have an aerolite.

If the body is so small or so fusible as to be dissipated in the upper regions of the atmosphere, we have a shooting-star.

A crowd of such bodies sufficiently dense to be seen in the sunlight constitutes a comet.

A group less dense will be entirely invisible unless the earth happens to pass through it, when we shall have a meteoric shower.

In accordance with a proposal of Professor Newton, we shall call these bodies by the general name of "meteoroids."

Thus one simple hypothesis accounts for at least three seemingly diverse phenomena. To show this clearly, the mechanical theory of heat, with some of its attendant physical facts, must be brought to our aid. It is now established that heat is a certain form of motion, that hot air differs from cold air only in a more rapid vibration of its molecules, and that it communicates its heat to solid bodies simply by striking them with its molecules. If, then, a body moves rapidly through the air, the mere impact of the aerial molecules ought to warm it just as

hot air would. This result of theory has been proved correct by the researches of Professor William Thomson and others. A thermometer being placed in front of a rapidly moving body rose one degree when the body moved through the air at the rate of one hundred and twenty-five feet per second, and with higher velocities the rise was as the square of the velocity, so that a velocity of 250 feet produced a rise of 4°; of 375 feet, 9°; of 500 feet, 16°; and so on.

The earth moves in its orbit at the rate of 98,000 feet per second, which is the velocity with which the air would strike a body at rest in the planetary spaces. This velocity would produce a rise of temperature of 600,000 degrees. Such a body would therefore be suddenly exposed to a temperature far above any the chemist can produce by the most powerful agents. If, as will commonly be the case, the meteoroid is moving to meet the earth, the relative velocity, and therefore the temperature, will be yet higher. The November meteors, for instance, strike the atmosphere with a relative velocity of forty-four miles per second, which corresponds to a temperature of three million degrees Fahrenheit! Exposed to such a temperature, neither great size nor combustibility are necessary to account for both the brilliancy and brevity of their course. In fact, Professor Harkness, of the United States Naval Observatory, calculates that, if we suppose the ratio of light to heat to be the same as in the Drummond light, a meteoroid weighing but a single grain would give light enough to shine like a star of the first magnitude at the distance of one hundred and twenty miles.

We have alluded to the fact, that in a meteoric shower, if the paths of the individual meteors are produced backward, they are all found to pass through the same point of the heavens. This is called the "radiant point." The radiant point of the November meteors is in the constellation Leo, that of the August ones in Perseus. It appears in the same position wherever the observer is situated, and it does not partake of the diurnal motion of the earth. These two facts prove the theory that meteoric showers are caused by the earth encountering a group of particles moving independently in the planetary spaces. The meteors really move in parallel straight lines,

like drops of rain in a shower, and the radiant point is simply an effect of perspective, which makes these lines appear to converge toward a vanishing point, like the streets of a city in a perspective view. The best visible illustration of this appearance will perhaps be afforded by watching light flakes of snow fall during a calm. The flakes which are falling directly toward the observer do not seem to move at all. The surrounding flakes seem gradually to separate from these on all sides; those which are going to fall to the left seeming to move toward the left, and so with those which will fall toward the right, the front, or the rear. So with the meteoric showers. A meteor coming directly toward the observer does not seem to move at all, and the only point in which such a meteor can be seen is itself the radiant point. The surrounding meteors, though all falling in the same absolute direction, seem to diverge on all sides like the snow-flakes. If two other observers are situated at a considerable distance on either side of the first, a meteor falling directly toward the latter will to the left-hand observer seem to move off to the right, and to the right-hand observer off to the left, so that the two observers see the same meteor moving in apparently opposite directions.

The radiant point being that of the direction of the meteor-fall, it appears from actual observation that, when the earth arrives at a certain point of its orbit, we see an unusual number of meteors, falling in a direction which has never sensibly varied for at least a third of a century. This general fact proves our general proposition respecting the cause of meteoric showers in a manner both direct and indisputable.

The evidence that the sporadic shooting-stars, visible during every clear night, are caused by small bodies encountering the earth in its orbital motion is not of the same direct character, because these shooting-stars exhibit no definite radiant point. Still, the fact admits of no rational doubt. The appearance of sporadic meteors, and of those which fall in showers, are so exactly similar, that we cannot avoid attributing them to the same cause. Moreover, the existence of immense swarms of minute bodies moving in definite orbits through space being proved, it is highly probable *a priori* that many such bodies would be scattered at random.

We now approach one of the most curious and suggestive discoveries of recent astronomy, — a discovery resulting from such a series of independent and apparently disconnected observations, that no single individual can claim the credit of making it. We shall ask leave to tell the story from the beginning.

In December, 1865, M. Tempel, an astronomer of Marseilles, discovered a faint telescopic comet. It was afterward discovered independently by Mr. H. P. Tuttle, at the Naval Observatory, Washington. It passed its perihelion in January, and, receding from the sun, vanished from sight in March. It was soon found to move in an elliptic orbit with a period of something like thirty years. The process of reducing and publishing astronomical observations is, however, so slow and laborious that generally at least a year has to elapse before the material for the definitive determination of a cometary orbit can be collected. So it was not until January, 1867, that Dr. Oppalzer of Vienna was able to compute an accurate orbit of this comet. The number of the *Astronomische Nachrichten* which contains the details of his computation is dated on the 28th of that month.

Let us now return to our meteors. It is well known that a considerable meteoric shower was seen in Europe on the night of November 13 – 14, 1866. It being settled that this shower, like that of 1833, was caused by the earth encountering a group of small bodies, moving in a different orbit, astronomers were naturally anxious to determine this orbit. But the data for this determination were insufficient until the periodic time was known. This important element the researches of Professor Newton had left in doubt. The shower recurring at intervals of thirty-three years, it might, at first sight, seem that the time of revolution must be thirty-three years. But this conclusion would be hasty, because the group might have returned several times in the course of the thirty-three years, crossing the orbit of the earth at times when the latter was not near the point of intersection. Professor Newton was led to consider a period of $1\frac{1}{32}$ years rather more probable than the longer. At the same time he pointed out a fact which might lead to a definite solution of the problem. We have seen that as centuries elapsed the shower occurred on a later

and later day of the year, the date being October 19 in 902 and November 13 in 1866. This indicates a progressive motion of the node amounting to fifty-four seconds in a century. Now, what must be the periodic time in order that this change may be produced by the action of the planets? Professor John C. Adams solved this question, and gave thirty-three years for the answer.

The periodic time and the radiant point being known, the data for determining the orbit were completely given, — a fact which seems to have first occurred to Le Verrier. His solution was read to the French Academy of Sciences on January 21, 1867. The following are the elements of the orbit to which he was led: —

Period of revolution	33.25 years.
Semi-major axis	10.34
Eccentricity	0.9044
Perihelion distance	0.9890
Inclination of the orbit	14° 41′
Longitude of the node	51° 18′
Perihelion unknown, but near the node.	

Dr. Oppalzer's elements of Tempel's comet, as published in the *Astronomische Nachrichten* of January 28, 1867, are: —

Period of revolution	33.18 years.
Semi-major axis	10.32
Eccentricity	0.9054
Perihelion distance	0.9765
Inclination of the orbit	17° 18′
Longitude of the node	51° 26′
Longitude of the perihelion	42° 24′

The similarity of these two sets of numbers is too striking to be the result of chance. The "inclination" is the only element which differs sensibly, and this difference was afterward found by Le Verrier himself to proceed from his having adopted an erroneous position of the radiant point in his calculations. In estimating the similarity of the orbits, it must always be remembered that the two calculators were entirely ignorant of each other's results until they saw them in print, and that the coincidence was first detected by a third person, C. W. F. Peters of Altona, who compared the printed results in the two publications.

The inference to be drawn from these facts of observation is, that the November meteors are caused by a long stream of minute bodies following Tempel's comet in its orbit. Whenever the earth passes through this stream, all the atoms that it encounters are swept away as shooting-stars. Thus, millions of the particles of the stream are destroyed, or rather added to the earth every year. But so vast is the number of these bodies that ages will be required to make any appreciable diminution of their number. By rough estimates, the details of which we need not enter upon, it is supposed that the individual meteoroids of the November stream pass a given point at the rate of millions a second. Yet several years even are required for the passage of the thicker part of the stream, its entire length at perihelion not being less than a thousand million miles.

It is a curious fact that the orbit of the stream of meteoroids not only intersects the orbit of the earth, but passes in close proximity to that of Uranus. This fact led Le Verrier to the conclusion that the stream did not originally form part of our system, but was a wanderer through the stellar spaces, until, accidentally passing in close proximity to Uranus, the attraction of that planet threw it into an elliptic orbit round the sun. He even attempted, by calculating back the revolutions of the meteoric group and of Uranus, to fix the date of this event, and gave the year 126 of the Christian era as the most probable epoch of its occurrence.

While this date is somewhat problematical, the grouping of the meteoroids renders it almost certain that they have not been revolving in their present orbit during many centuries. For if we suppose a group of bodies, ever so close, to move round and round in a re-entering orbit, the slightly different velocities of the individuals will cause them gradually to spread out into a long stream, and this spreading will continue until the stream extends around the entire orbit. This may be illustrated by a race-course. If a number of horses start together and continue to run round and round the course, the fastest horse will leave the slowest behind until he is on the opposite side of the course. Then he will approach him from behind until he overtakes him. The horses will then be scat-

tered around the entire course. In the same way, when the swiftest meteoroid overtakes the slowest one the stream will be spread over the entire orbit. As this must happen in the course of centuries, and as the great body of the November meteoroids are included in one tenth the length of the orbit, it seems pretty certain that they have not had many centuries to scatter themselves.

Soon after the discovery of the connection of the November meteoroids with Tempel's comet was made known, an Italian astronomer, M. Schiaperelli, was fortunate enough to identify the orbit of the August meteoroids with that of a telescopic comet discovered in 1862. The orbits approach as closely as that of the November meteoroids to Tempel's comet. But the August meteoroids now seem to be spread around the entire orbit, the meteors of that month being about equally numerous every year.

It thus being rendered tolerably certain that the best known streams of meteoroids are composed of particles left behind by comets, the question naturally arises, What is the relation between these comets and the meteoroids? The answer which most readily suggests itself is, That the comets are themselves composed of meteoroids, which, it will be remembered, are simply detached particles of solid matter, moving through the celestial spaces singly or in groups. It must also be remembered that the comets of which we speak have no tail, but seem like nebulous patches so thin and airy that any attempt to shake pestilence and war from their hair would simply result in their shaking themselves to pieces. They do indeed appear to the observer to form a continuous mass of matter of extreme tenuity. But we know that clouds, steam, smoke, and other forms of matter presenting this appearance at the surface of the earth are really formed of detached particles, and the presumption is strong that the comet is formed in the same way. It is true that an elastic gas would present the same appearance. But it is difficult to conceive how a body of such a gas could escape being instantly dissipated by its own elasticity; so that, among known forms of matter, that of detached particles seems best to explain the appearance of telescopic comets.

This view is sustained by the interesting fact, observed in numerous instances, of the gradual decay of known periodic comets. The two most notable cases are those of the comets of Halley and Biela. The former returns to the sun every seventy-six years. At its apparition in 1456 it was described as a terrible object, having a tail sixty degrees in length. It inspired Pope Calixtus III. with such terror that he ordered prayers throughout Christendom against its malign influence, thus giving rise to the wide-spread fiction of "the bull against the comet." But, at its last two returns in 1759, and again in 1835, its appearance was in no way remarkable.

Biela's comet has been known for nearly a century, being first seen in 1772. But its periodicity was not recognized until 1826, when it was found to return to its perihelion every six years and a half. In 1846 it became celebrated for an appearance altogether new in the history of astronomy, being separated into two parts. In the autumn of 1852 both parts were observed for the last time, and were very faint. The next return took place when the earth was on the opposite side of the sun, so that the comet could not be seen. In 1865, when its return in close proximity to the earth was to have been expected, not a trace of it could be seen, though looked for under the most favorable circumstances by the best observers, and with good telescopes. After showing itself for eighty years, it vanished from sight like a shadow. No doubt the individual particles of the comet are still revolving in their accustomed orbit; but in the course of successive revolutions they have become so widely dispersed as to be no longer visible.

Professor Newton describes the meteoroids as being apparently the material out of which worlds are forming. Although we cannot see how a world can be formed out of these materials, we do catch glimpses of a possible process by which they are being increased. Great clouds of diffused and finely divided matter are moving in all directions in the stellar spaces. Accidentally entering our system, some of them are thrown into elliptic orbits by the attraction of a planet. Such of these as come within range of our telescopes appear as comets of long period, and become permanent members of our system. In

the lapse of ages the great perturbations to which they are exposed prove too strong for the feeble bond of central attraction, and the component particles are gradually drawn off to move in varying orbits. At length they strike the atmosphere of some planet, when their career of millions of ages brilliantly terminates in a shooting-star.

Professor Newton estimates the number of shooting-stars which enter the earth's atmosphere daily at seven millions. Their average mass appears to be a fraction of a grain, — say one third. We may therefore roughly estimate the amount of matter daily added to the earth in the way we have described at three hundred pounds, or one cubic foot. At this rate it would require seven millions of millions of years to increase the diameter of the earth by a single foot. It is easy to recognize the mythical character of the supposed "meteoric dust" which has been collected on dinner-plates after meteoric showers. All such *débris* as would fall on a plate an acre in extent could hardly be weighed in a balance.

It does not seem extravagant to hope that shooting-stars may yet throw some light on the grandest problem now presented to the human mind, — the origin of the universe. Is the present arrangement of the stellar and planetary systems fitted to exist from eternity to eternity? Did it spring ready made from the hand of the Creator? Or did it condense from a nebulous gas in periods of time compared with which the ages of geology are but moments? The modern discoveries and theories in physics and astronomy all seem to tend toward the solution of these questions, and we may believe that their answer will be found within the power of the human intellect.

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